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FEB 16 1970

PERSONAL COMMUNICATION FROM THE AUTHORS

DDT RESIDUES IN PACIFIC MARINE FISH

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MONS 064506

ABSTRACT

Analysis of fish from the eastern Pacific Ocean, the coastal waters of California and San Francisco Bay show that DDT concentrations in many marine fish are equivalent to or higher than the DDT concentrations in fresh water fish from North America. Concentrations were found to be highest off southern California. DDT residues in this area could not be related to input from agricultural drainage waters and are assumed to be derived from aerial fallout with an unknown contribution from urban run off. High DDT residues might persist in this area for many years.

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In 1969 shipments of canned jack mackerel, Trachurus symmetricus, were seized and condemned by the Food and Drug Administration. The fish had been caught in the Pacific Ocean off the coast of southern California and were found to contain up to 10 parts per million of total DDT compounds in their tissues on a net weight basis. The maximum amount of the DDT compounds permitted in fish shipped in interstate commerce is now five parts per million. On a lipid weight basis, on which the tolerance for beef has been established, permitted residues in fish would therefore range up to 100 parts per million in fish preparations containing 5% fat.

Monitoring programs for agricultural and industrial pollutants have usually been confined to areas or commodities close to the sites of application. The serious and unsuspected contamination of a marine fishery indicates, however, that the existing monitoring programs may not have been adequately designed to measure the rates of entry and accumulation of pollutants into the total environment. Marine birds over wide areas of the sea now contain higher concentrations of the DDT compounds and also, in some cases, of the polychlorinated biphenyls than do bird species of terrestrial ecosystems (1,2). In 1969 the reason for reproductive failures of fish-eating marine birds in southern California became apparent when it was discovered that these species were unable to produce eggs with normal shells. The amounts of the DDT compounds in these eggs were very high, up to 2,500 ppm on a lipid basis in eggs of the brown pelican Pelecanus occidentalis (3). Other marine fisheries within this area may therefore also be considerably contaminated.

The study reported in this paper was begun in 1965 under a contract with the Bureau of Commercial Fisheries and the original analyses were completed in early 1966. Publication of the results was delayed when it became apparent that unidentified compounds in the extracts might have interfered with the determination of one or more of the DDT compounds. The analytical methods were therefore revised in 1967 and the extracts were reanalysed to determine the extent of interference. The unknown compounds were identified as polychlorinated biphenyls through work in Sweden which had determined the identity of similar pollutants by means of techniques in which gas-liquid chromatography was combined with mass spectrometry (4,5,6). The polychlorinated biphenyls (PCBs) are chlorinated hydrocarbons of industrial origin. The concentrations of PCBs measured in the fish samples discussed here have been published elsewhere (1).

Methods and Materials

Whenever possible at least 15 specimens of each species were obtained from each locality. Fish were promptly frozen and stored at -15° C until analysis. Each fish was analysed individually.

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Lipids were extracted by either of two different methods which yielded equivalent determinations of the DDT compounds. By the method of Stanley and Lefavoure (7) the whole fish was digested with a mixture of acetic and perchloric acids. The lipids were subsequently extracted from the diluted digestion mixture with petroleum ether. By the method of Bligh and Dyer (9,8), the fish or a portion thereof was macerated in a Waring blender with a mixture of chloroform and methanol which was made di-phasic by the addition of water. The lipids and the chlorinated hydrocarbons remain in the chloroform phase.

Partitioning of lipid preparations with acetonitrile and either hexane or petroleum ether may result in significant losses of the polychlorinated biphenyls. The DDT compounds, dieldrin, and endrin are selectively partitioned into the acetonitrile phase but 50% or more of the PCBs may remain in the petroleum ether layer. Raynolds has reported that PCBs may be eluted from florisil columns with hexane (9). We also have observed that PCBs are readily eluted from florisil with either hexane or petroleum ether. A combination of acetonitrile partitioning and preliminary washing of the extract on the column with hexane or petroleum ether may therefore remove virtually all of the PCBs from a preparation, possibly accounting for the failures of some investigators to detect them.

MONS 064510

Lipids were removed from extracts by passage through a modified Davidow column (7). Unlike the florisil cleanup method, this procedure imposes no practical limitation on the amounts of lipid that may be treated. An extract may therefore be obtained from an entire fish of considerable size and pollutants present in relatively small amounts may be detected and measured. Aldrin, dialdrin and endrin are, however, destroyed by the strong acid mixture in the column. Dieldrin has been recorded in marine fish-eating birds from the eastern Pacific (3) and both dialdrin and endrin are present in marine fish-eating birds from the Gulf of California and Florida (2,3). These compounds must therefore be present also in the fish prey species but they were not measured in the present study.

Three gas chromatographs were used at successive stages of the project. F&M Scientific Corporation Models 400 and 402 and a Microtek 220 were equipped with all glass systems and with tritium or nickel-63 electron capture detectors. Different columns were used at different times but most determinations were made with 3% OF-1 on hexamethyldisilazane-treated Chromosorb W, 80-100 mesh. 5% SE-30, 10% DC-200, and mixtures of these with QF-1, on the same support or on Gas Chrom Q were also used, mainly for confirmation. Argon-methane (95%-5%) was used as the carrier gas for the F&M equipment and nitrogen for the Microtek 220.

In all extracts the amounts of o,p'-DDE were significantly greater than the amounts of the PCBs with similar retention times. No values of DDE were found to be incorrect therefore because of PCB interference, since the error introduced by the presence of PCB was less than experimental error. The identification of DDE was based primarily upon a comparison of retention times of peaks on gas chromatograms obtained with each kind of column with those produced by standards and upon a comparison of Rf values obtained on thin-layer chromatograms.

Silica-gel G plates, activated at 105° were used for the thin layer chromatography. N-hexane, 10% (v/v) cyclohexane in petroleum ether, and 10% (v/v) ethyl ether in petroleum ether were used as solvents in one-dimensional chromatograms. Areas of the plates were scraped off, washed with petroleum ether, and the eluate was analysed with the gas chromatograph. DDE tends to migrate near the solvent front with the PCBs. Preliminary thin-layer separations are routinely used in some laboratories to separate the PCBs from the majority of the compounds derived from insecticides (10).

On the OF-1 columns, and also on OV-210 columns, there is no significant interference between any of the PCB compounds and p,p'-DDT. Since the original measurements were performed with a OF-1 column, there was no need to correct p,p'-DDT values for PCB interference. The p,p'-DDT removed from the thin layer plates was saponified (11) and the compound recorded as p,p'-DDT was quantitatively converted to a compound with the chromatographic characteristics of p,p'-DDE. On the non-polar DC-200 and SE-30 columns there was significant interference between a PCB compound and p,p'-DDT, the significance of the interference depending on the relative abundance of each compound.

Interference was found in the determination of p,p'-DDD on both groups of columns and in some cases it was necessary to recalculate the DDD values. The DDD was determined by a comparison of chromatograms of the original and of saponified extracts. The saponification technique does not destroy this and most PCB compounds and the PCB profile remains therefore largely unchanged after saponification but the peak representing a mixture of DDD and a PCB is reduced in height in relation to other PCB peaks following saponification, depending on the relative amount of each compound. DDD can therefore be estimated from this reduction in peak height. Saponification of the thin layer isolate from the DDD region results in the conversion of the DDD to its ethylene derivative, DDMU. With this technique the identity of the compound suspected of being DDD can be confirmed.

The DDT isomer, o,p'-DDT, was also present in some extracts and was identified from retention times on gas chromatograms and by the conversion of its thin layer isolate to a compound with the chromatographic characteristics of o,p'-DDE, the ethylene derivative. PCB compounds have retention times similar to o,p'-DDT on both non-polar and polar columns.

Two PCBs have retention times similar to those of the ethylene derivatives DDMU and o,p'-DDE and it was not therefore feasible to attempt to quantify these compounds. When the amount of PCB is relatively small the peaks may not be evident at dilutions that produce conspicuous peaks of the DDT compounds. Under these conditions the peaks thought to represent DDMU and o,p'-DDE were most likely not PCB. Confirmation of identity through such techniques as mass spectrometry is becoming increasingly important as additional pollutants are identified in extracts of wildlife. Identification of PCBs in two bald eagles, a fish-eating species, has been accomplished with this technique by the U. S. Bureau of Sport Fisheries and Wildlife (12). In this paper only the values of p,p'-DDE, p,p'-DDD and p,p'-DDT are reported. "DDT residues" are defined to consist of any combination of these three compounds.

Results and Discussion

In Table 1 are listed the values of DDT residues found in collections of the Northern Anchovy, Engraulis mordax, Jack Mackerel, Trachurus symmetricus, Hake, Merluccius productus, Shiner Perch, Cymatogaster aggregata, and English Sole, Parophrys vetulus. Residues found in six species of rockfish, Sebastodes, are given in Table 2 and residues found in the blue fin tuna, Thunnus thynnus, yellow fin tuna (Thunnus albacares) and skipjack tuna (Euthynnus pelamis) are given in Table 3.

MONS 064514

San Francisco Bay receives the drainage waters from the Sacramento and San Joaquin valleys which comprise the principal agricultural areas of California. A monitoring program for the chlorinated hydrocarbons of pesticide origin carried out in 1964 and 1965 in the surface waters at several locations in San Francisco Bay and incoming rivers showed that average total concentrations of DDE plus DDD plus DDT were in the order of 0.1 micrograms per liter or 100 parts per trillion (13). The median value of the amount of flow into San Francisco Bay from the delta area is estimated to be 15,422,000 acre-feet per year (14) or 1.9×10^{13} liters. Input of the DDT compounds into San Francisco Bay from the Sacramento and San Joaquin rivers has therefore been in the order of 1900 kg per year. This is a very small fraction of the amount of DDT that has been applied in California.

The concentration of 100 parts per trillion of the DDT compounds in the water of San Francisco Bay is only 10 times less than the solubility (15). Some is presumably in solution and the remainder adsorbed to small particulate matter. This is to be compared with the concentrations found in the fish from San Francisco Bay, presented in Table I. Average concentrations in collections of the Northern Anchovy were 0.29 ± 0.04 and 0.51 ± 0.10 ppm of the whole fish, 0.42 ± 0.04 and 0.44 ± 0.08 ppm in the English Sole, and 1.11 ± 0.57, 0.84 ± 0.10, 1.17 ± 0.20 and 0.86 ± 0.10 in the Shiner Perch (95% confidence limits). Concentrations in the fish were therefore about four orders of magnitude higher than those in the water. Oysters have been found to accumulate DDT to levels 70,000 times those in the water (16).

In spite of the vast amounts of work devoted to the movements of the chlorinated hydrocarbons through aqueous ecosystems it is not yet clear whether situations are achieved whereby concentrations in the lipids of a given species are in equilibrium with much lower concentrations in solution in the ambient water. If this were the case the ratio between the concentration in the lipid and the concentration in the water would resemble a partition coefficient. Increased input of a chlorinated hydrocarbon into the ecosystem would result in higher concentrations in both water and lipid. Fish entering cleaner water might therefore be expected to lose some of their residue burdens, just as shellfish may purge themselves of residues when placed in cleaner water. The concentrations measured in shellfish are therefore assumed to reflect local background levels (17). Abundant data show that the chlorinated hydrocarbon compounds leave the water phase to be selectively accumulated in the lipids of biological systems and that there is tropic concentration along food chains with occasionally very high amounts in fish-eating birds. However, the birds represent only a small fraction of the total biomass. The total amount, as distinguished from the concentration, of a chlorinated hydrocarbon in another component of the biomass lower in the food chain could be much higher than that in the terminal carnivores. The available data do not permit us to discount the possibility that the greater part of the chlorinated hydrocarbons in an aqueous ecosystem could be in the water, mud, sediments and other non-living components. Monitoring data would be more meaningful if they could estimate yields of what fraction of the chlorinated hydrocarbons occurs in each component of the biomass and also in the inanimate components. DDD residues persisted in the Clear Lake ecosystem for many years after the last application (18). Water and mud might therefore constitute reservoirs which could transmit chlorinated hydrocarbons into food chains over long periods of time.

MONS 064516

An understanding of these phenomena would be invaluable in interpreting the significance of the higher amounts of the DDT compounds in the fish in the marine waters of southern California and in predicting what concentrations might be expected in the future. The average DDT concentrations in the San Francisco Bay anchovies were 0.29 and 0.51 ppm, but concentrations tended to be larger in collections from the coastal waters to the south. Average concentrations in the Northern Anchovy collections from Monterey, Morro Bay, Port Hueneme, and Terminal Island were 0.81 ± 0.20, 0.67 ± 0.21, 2.70 ± 0.79 and 12.3 ± 2.5 respectively (Table I, 95% confidence limits). The two collections of Jack Mackerel analysed, consisting of 31 and 16 fish respectively from the Cortez Bank near the Channel Islands and Monterey both contained on average less than a part per million (Table I).

Higher concentrations of the DDT compounds in the Jack Mackerel caught in 1969 may therefore mean that overall levels in this area of the sea are still increasing. There was a significant correlation between the thickness of the shells of eggs of the Brown Pelican from Anacapa Island in 1969 and the concentrations in the yolk lipid of DDE (3). Young birds were still being produced by the Brown Pelicans on Anacapa in 1963 and 1964 (19) but eggs collected in 1962 already showed signs of shell thinning (20). The implication is that the DDE concentrations in the pelicans in 1963 and 1964 were sufficiently low so that eggshell thinning was still below a critical level and the eggs did not break. It is unfortunate that none of the monitoring programs now in effect have been designed to answer the question whether these compounds are accumulating in the total environment and at what rates, a deficiency that might now be corrected.

MONS 064517

At a concentration of one part per trillion, 100 times lower than the amounts measured in San Francisco Bay, a volume of water 1000 km square and 100 meters deep, a volume approximately equivalent to the surface coastal waters of California, would contain 100,000 kg of DDT. This is about 50 times greater than the amount estimated to enter San Francisco Bay from the Agricultural drainage waters. No major river enters the sea in southern California and the major sources of DDT in the local marine ecosystem would therefore be currents bringing the DDT from elsewhere, aerial fallout, and runoff in urban sewage. It is unlikely that agriculture drainage could be the major source of input because of the low solubility of DDT in water and because of the relatively low amounts entering San Francisco Bay. The contribution of urban sewage might be significant especially when the factory manufacturing most of the DDT produced in the United States is in the Los Angeles area. The high concentrations of both DDT and PCB in the surface-feeding sea birds around the world (2) and the demonstration that DDT may enter the sea in significant quantities by dry fallout (21) and by fallout in rain (22) suggest that aerial fallout is also contributing to the DDT residues in the marine ecosystem of southern California. DDT readily co-distills with water to enter the atmosphere as a vapor (23) and also readily volatilizes from dry particulate material (24). It has been found associated with airborne particulates in air over Pittsburgh (24) and London (25), as well as airborne particulates in marine air (21). DDT readily adsorbs to particulate material. Areas such as southern California with high amounts of smog might therefore act as traps for DDT in the vapor phase coming from anywhere in the world. The DDT would then fallout into the sea or into the watershed with the components of smog. Since vast amounts of DDT are still present in the land reservoirs around the world and will continue to volatilize into the air, input into the coastal waters might increase over the next few years. If the estimated 100,000 kg

were low by an order of magnitude, a million kilograms or two million pounds is still only a fraction of the DDT that has been applied to California each year for many years.

MONS 064519

U. S. production of DDT is now about 140 million pounds or 6×10^{10} grams. World production is therefore in the order of 10^{11} grams per year. Since the DDT compounds have been released into the environment over the past 25 years and have a long half-life possibly approximately 10^{12} grams of DDT are now in the world environment. The primary productivity of the oceans is in the order of 2×10^{16} gm of carbon incorporated into phytoplankton per year (26). The amount of DDT, or of other persistent pollutants released in comparable amounts into the environment, is clearly not trivial in relation to the capacity of the environment. High concentrations in marine fish or birds might therefore have been expected.

With a volume of about 350 million cubic miles or 15×10^{20} liters, the oceans are just large enough to dissolve all the estimated DDT compounds at a concentration of one part per trillion. Local concentrations at the surface might be considerably higher. Fish might therefore remain contaiminated for decades.

MONS 064520

Of the DDT compounds in marine fish, p, p'-DDE is by far the most abundant and usually constitutes more than half of the total DDT residues (Tables I, II, III). It is also the most abundant of the chlorinated hydrocarbons in the marine birds. Concentrations as high as 2,500 ppm in the fat of Brown Pelicans (3) suggest that the rate of degradation of this compound in the sea is minimal at best and to date it apparently has not been demonstrated that this compound is degraded by any marine organism. In the knowledge of the authors only one study has so far shown that DDE can be degraded by a microorganism to an unknown derivative (27). DDD, the other principal derivative of p,p'-DDT is readily degraded to other compounds in both the rat (28) and the pigeon (29). Long thought to be relatively non-toxic, DDE is now known to inhibit one or more ATPases (30), to increase the activity of microsomal enzymes (2) and may also inhibit carbonic anhydrase under certain conditions (31). Moreover it is now considered to be the compound principally responsible for the production of thin-shelled eggs by many species of birds (32), including those in the coastal waters of California (3).

In the fish from San Francisco Bay, however, DDE constitutes less than half of the total DDT residue (Table I). DDE also constitutes less than half of the total DDT residues found in water from most of the localities samples in the Bay (13).

In Table II are presented the residue concentrations found in six species of rockfish, Sebastodes, from the Monterey region. The average total concentrations were 0.324, 0.481, 0.563, 0.571, 0.739 and 1.99 parts per million. Although these rockfish were considerably larger than the Jack Mackerel, Northern Anchovies and English Sole sampled from the Monterey area (Table I) and might be considered to be somewhat higher in the food chain, the residue concentrations in both groups of fish are essentially equivalent. The residues in Jack Mackerel averaged 0.23 ± 0.04 and 0.63 ± 0.07 ppm, in English Sole 0.658 ± 0.126 ppm and in the Northern Anchovies 0.81 ± 0.20 ppm.

The total parts per million concentrations were correlated with the size of the fish in all collections where the total fish was analysed and in the blue fin tuna samples. Only in the blue fin tuna was there a significant increase in residue concentrations with increasing size of the fish (Table IV). In three instances, moreover, concentration, as distinguished from content, decreased significantly with increasing fish size. These were the Jack Mackerel from Cortez Bank (r = 0.6632, P <0.001, regression coefficient -0.0045 ± 0.0019) the Northern Anchovy from Morro Bay (r = 0.5125, P <0.001, regression coefficient -0.0722 ± 0.0467) and the English Sole from Monterey (r = 0.5158, P <0.05, regression coefficient -0.0029 ± 0.0028). We did not measure lipid concentrations in these samples.

All collections from San Francisco Bay showed a significant increase in DDT content with increasing fish size with the slope of the regression line positive and significantly different from zero. Only one of the ocean collections, however, the Jack Mackerel from Monterey, had a correlation coefficient significant at the 95% level. In all other ocean collections the regression line was not significantly different from zero. In part this may be due to the size homogeneity of some samples which would tend to mask size-dependent variations, but it may also reflect different past exposures to the DDT compounds. More data, with lipid measurements are needed to clarify this point. Neither weight or length were related to the concentrations of chlorinated hydrocarbons in Yellow Perch, Perca flavescens, and Pumpkinseed (Lepomis gibbosus) from Massachusetts (33).

MONS 064523

The similarity in total residue concentrations among the various fish species from Monterey and the failure to find increases in residue concentrations with increasing size and in some cases the failure to find increases in total residue content with increasing size are consistant with the theory that DDT residues in fish are in some kind of equilibrium with the chlorinated hydrocarbons dissolved in the water. When DDT is applied to water in concentrations above the solubility it may be taken up rapidly by fish through the gills and the external mucous coat and may build up to high concentrations in the body tissues (34). In other experiments fish exposed to concentrations above the solubility accumulate DDT residues, but lose some of them to the medium when transferred to clean water (35). When brook trout (Salvelinus fontinalis) were continuously exposed to DDT concentrations of 3 parts per trillion in water, a concentration well below the maximum solubility for 120 days, the whole body contained only 0.025 ppm (36). Marine fish most likely acquire most of their residues, therefore, in their food supply. The ratio between 3 parts per trillion in the water and 0.025 ppm in the fish is approximately the same as 100 parts per trillion in San Francisco Bay water and 1 ppm in fish from the Bay. The observed relationship between weight, concentration, and concentration, and content are consistent with the theory that some ocean fish are constantly losing residues, acquired with their food, back to the water because of the partition coefficient phenomenon.

MONS 064524

The seizure of the canned Jack Mackerel shipments and increasing interest in marine pollution will undoubtedly lead to various monitoring programs with considerable expenditure of funds and manpower. It is hoped that these programs will be so designed that they will also answer several basic questions about the movements of these compounds along food chains and through the various components of the ecosystem rather than determining only whether or not a given series of fish contains more or less than five parts per million of the DDT compounds.

The only controlled experimental studies so far on the effects of low levels of DDT upon the reproduction of fish were done with a fresh water species, the Brook Trout (37). Whole body levels in the adults comparable to those in the anchovies from Terminal Island (Table I) were associated with increased mortality of the fry at the time when the yolk fat was rapidly utilized. In the absence of sufficient residue data and of controlled experiments it is perhaps not profitable to speculate whether any marine fish are yet adversely affected by the present levels of DDT contamination. The fry of most species are planktonic and experience a natural high mortality. Since the present levels of contamination are now affecting the birds at the very top of the marine food chain, the possibility exists that they might affect other levels as well.

When Brook Trout containing total DDT concentrations in the order of 14 ppm on a wet weight basis were subjected to stress through partial starvation the mortality rate greatly increased over that of controls subjected to the same conditions (38). A combination of environmental stresses such as starvation, changing temperatures and possibly the physiological stresses associated with spawning might therefore have adverse effects upon populations of marine fish with current levels of DDT contamination.

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Acknowledgments

The study was supported by the Bureau of Commercial Fisheries and we thank Dr. Philip Butler for his advice and encouragement. Additional work was supported by the National Science Foundation grants GB 6362 and GB 11649. For assistance in obtaining specimens for analysis we are indebted to Mr. Frank Alverson, Mr. Lloyd Austin, Professor T. F. Cooper, Dr. R. E. Gottshaw, M. Denis Larrivee, Mr. Robert Lea, Dr. M. S. Olcott, Mr. Eugene Nakamura, Mr. Max Patashnik and Dr. E. Glen Richards. We fondly acknowledge the participation of Miss Edith Engelson, Miss Linda Fuchs and Miss Brigitte Morgenbrodt.

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Table 1. DDT Residues in Pacific Marine Fish

Species	Northern Anchovy, Engraulis mordax		
Locality, date	San Francisco Bay July 29, 1965	San Francisco Bay Nov. 4, 1965	Monterey Bay Nov. 30, 1965
N	17	29	30
Weight, grams	12.4 ±2.3	3.97 ±0.26	26.5 ±1.2
p,p'-DDE parts per million	0.21 ±0.05	0.11 ±0.01	0.68 ±0.19
p,p'-DDD parts per million	0.19 ±0.04	0.10 ±0.02	0.06 ±0.01
p,p'-DDT parts per million	0.12 ±0.02	0.08 ±0.01	0.07 ±0.01
Total DDT parts per million	0.51 ±0.10	0.29 ±0.04	0.81 ±0.20
Total DDT micrograms	6.69 ±2.41	1.19 ±0.17	21.2 ±5.0
Concentration, ppm, versus weight			
Correlation coefficient, r, P	0.4217, P>0.05	0.1476, P>0.05	0.2297, P>0.1
Regression coefficient	0.0193 ±0.0220	0.0222 ±0.0567	-0.0373 ±0.0600
DDT content, micrograms versus weight			
Correlation coefficient (r), P	0.8283, P < 0.001	0.4990, P < 0.01	0.0774, P>0.1
Regression coefficient	0.8651 ±0.3114	0.3259 ±0.2192	-0.3204 ±1.5632

MCNS 064531

	Northern Anchovy		Jack Mackerel, Trachurus symmetricu
Morro Bay June 16, 1965	Port Hueneme Feb. 24, 1966	Terminal Island June 25, 1965	Monterey June 16, 1965
29	15	44	3
25.3 ±1.5	11.6 ±3.5	11.7 ±0.7	24.7 ±1.7
0.45 ±0.13	2.44 ±0.77	10.2 ±2.1	0.17 ±0.10
0.063 ±0.032	0.14 ±0.08	1.35 ±0.27	0.023 ±0.007
0.16 ±0.06	0.12 ±0.07	0.75 ±0.16	0.035 ±0.012
0.67 ±0.21	2.70 ±0.79	12.30 ±2.48	0.23 ±0.04
15.8 ±3.8	26.83 ±7.75	144.7 ±31.6	5.69 ±1.34
0.5125, $P < 0.01$	0.4503, $P > 0.05$	0.0529, $P > 0.1$	0.3271, $P > 0.1$
-0.0722 ±0.0467	-0.1013 ±0.1160	0.1916 ±1.0877	0.0085 ±0.2159
0.3187, $P > 0.05$	0.3810, $P > 0.1$	0.2501, $P > 0.05$	0.5883, $P > 0.1$
-0.8021 ±0.9248	0.8407 ±1.1774	11.4402 ±13.4854	0.4565 ±5.6385

MONS 064532

Jack Mackerel		Hake, *Merluccius productus*	
Cortez Bank Nov. 22, 1965	Monterey Feb. 25, 1966	Puget Sound Jan. 29, 1966	Santa Barbara Feb. 24, 1966
31	16	22	6
81.8 ±8.3	20.80 ±2.39	281.3 ±17.5	384 ±270
0.32 ±0.06	0.45 ±0.04	0.04. ±0.012	1.22 ±0.75
0.063 ±0.013	0.07 ±0.01	0.060 ±0.016	0.168 ±0.157
0.087 ±0.016	0.11 ±0.04	0.061 ±0.016	0.141 ±0.089
0.47 ±0.05	0.63 ±0.07	0.162 ±0.039	1.53 ±0.70
36.67 ±3.40	13.37 ±2.38	46.0 ±12.3	481.8 ±402.9
0.6632, $P < 0.001$	0.2974, $P > 0.1$	0.1216, $P > 0.1$	0.4267, $P > 0.1$
-0.0045 ±0.0019	0.0085 ±0.0151	0.0002 ±0.0010	-0.0011 ±0.0029
0.0871, $P > 0.1$	0.8668, $P < 0.001$	0.2798, $P > 0.1$	0.3758, $P > 0.1$
0.0359 ±0.1527	0.8616 ±0.2744	0.1960 0.3062	0.5594 ±1.6814

MONS 064533

English Sole, Parophrys vetulus

San Francisco Bay July 29, 1965	San Francisco Bay Nov. 4, 1965	San Francisco Lightship Dec. 1, 1965	Monterey Feb. 15, 1966
18	33	15	15
14.3 ±3.7	17.3 ±3.2	253 ±19	195 ±36
0.141 ±0.018	0.131 ±0.126	0.116 ±0.033	0.533 ±0.129
0.168 ±0.020	0.142 ±0.028	0.032 ±0.008	0.063 ±0.014
0.115 ±0.022	0.162 ±0.040	0.017 ±0.003	0.062 ±0.016
0.424 ±0.044	0.435 ±0.082	0.165 ±0.035	0.658 ±0.126
5.94 ±1.49	6.77 ±1.10	41.0 ±8.4	126.3 ±20.0
0.1244, $P>0.1$	0.3330, $P>0.05$	0.3712, $P>0.1$	0.5158, $P<0.05$
-0.0015 ±0.0062	-0.0086 ±0.0087	-0.007 0.0010	-0.0029 ±0.0028
0.8098, $P<0.001$	0.5592, $P>0.01$	0.0447, $P>0.1$	0.3383, $P>0.1$
0.3202 ±0.1200	0.1932 ±0.1027	-0.0199 ±0.2507	0.2949 ±0.4701

MONS 064534

Shiner Perch, Cymatogaster aggregata

San Francisco Bay July 29, 1965	San Francisco Bay Oct. 20, 1965	San Francisco Bay Oct. 20, 1965	San Francisco Bay
14	14	10	13
11.1 ±5.0	5.50 ±0.67	26.70 ±7.65	15.3 ±5.1
0.40 ±0.25	0.28 ±0.03	0.49 ±0.13	0.35 ±0.04
0.40 ±0.19	0.30 ±0.03	0.40 ±0.07	0.28 ±0.04
0.34 ±0.27	0.26 ±0.04	0.28 ±0.05	0.24 ±0.05
1.11 ±0.57	0.84 ±0.10	1.17 ±0.20	0.86 ±0.10
11.2 ±5.8	4.69 ±0.86	33.3 ±12.6	13.8 ±5.8
0.1178, $P>0.1$	0.2059, $P>0.1$	0.5685, $P>0.05$	0.2969, $P>0.1$
-0.0135 ±0.0690	0.0289 ±0.0831	0.0148 ±0.0165	0.0056 ±0.0109
0.8928, $P<0.001$	0.7913, $P<0.001$	0.9440, $P<0.001$	0.9809, $P<0.001$
1.0540 ±0.3212	1.0137 ±0.5192	1.5596 ±0.5192	1.1297 ±0.1339

MGNS 064535

Table 2. DDT Residues in some Rockfishes, Sebastodes. Taken by Spear Gun, 50-75 Feet, Mouth of Carmel River, Carmel, California, Aug. 14, 1966.

Species Mean Wt (gm)	N	p,p'-DDE	p,p'-DDD	p,p'-DDT	Total DDT
S. caurinus 651 gm	1	0.446	0.058	0.059	0.563
S. mystinus 911 gm	1	0.520	0.110	0.109	0.739
S. melanops 808 gm	1	0.380	0.056	0.045	0.481
S. serranoides 673(500-767) gm	3	1.50 (0.53-2.01)	0.23 (0.11-0.29)	0.26 (0.073-0.36)	1.99 (0.71-2.66)
S. atrovirens 591(521-673) gm	6	0.444 (0.366-0.622)	0.067 (0.052-0.079)	0.060 (0.049-0.073)	0.571 (0.467-0.774)
S. carnatus 459(342-646) gm	3	0.259 (0.185-0.316)	0.032 (0.022-0.042)	0.034 (0.027-0.041)	0.324 (0.234-0.379)

MONS 064536

Table 3. DDT Residues in Tuna, Parts Per Million, Wet Weight

Species, Locality Tissue	N	DDE	DDD	p,p'-DDT	Total
Bluefin Tuna, Isla Geronimo, Baja California August 29, 1965					
liver	9	0.100 ±0.094	0.029 ±0.011	0.027 ±0.013	0.166 ±0.122
x-section[a]	7	0.245 ±0.182	0.040 ±0.010	0.166 ±0.090	0.451 ±0.201
total viscera, except liver	4	0.049 ±0.076	0.010 ±0.007	0.031 ±0.025	0.090 ±0.085
Yellowfin Tuna, Isla Geronimo, Baja California August 30, 1965					
liver	2	0.061	0.017	0.027	0.105 (0.062-0.147)
total viscera, except liver	2	0.021	0.005	0.017	0.043 (0.034-0.052)
x-section[a]	2	0.041	0.007	0.024	0.072 (0.055-0.89)
Central America (90°W, 8°N) August 23, 1965					
liver[c]	13	0.188 ±0.060	0.233 ±0.077	0.143 ±0.047	0.564 ±0.178
Galapagos Islands Nov. 6, 1965					
liver[c]	13	0.009 ±0.003	0.012 ±0.007	0.030 ±0.010	0.051 ±0.018

MONS 064537

Table 3, continued

Species, Locality Tissue	N	DDE	DDD	p,p'-DDT	Total
Skipjack Tuna off Honolulu November, 1965					
total viscera	11	0.012 ±0.004	0.021 ±0.008	0.017 ±0.003	0.050 ±0.015
liver	3	0.013	0.020	0.024	0.057 (0.040-0.093)
exterior muscle[b]	13	0.009 ±0.002	0.011 ±0.005	0.023 ±0.005	0.043 ±0.012
interior muscle[b]	13	0.002 ±0.001	0.003 ±0.001	0.006 ±0.001	0.011 ±0.004
Skipjack Tuna Galapagos Islands Oct.-Nov., 1965					
liver[c]	25	0.006 ±0.001	0.009 ±0.002	0.038 ±0.022	0.052 0.023
off Cape Pasado, Ecudor Sept. 1, 1965					
liver[c]	12	0.006 ±0.003	0.012 ±0.004	0.011 ±0.004	0.029 0.009

[a] Including skin but excluding viscera

[b] Exterior muscle included skin and subcutaneous fat; interior muscle contained neither skin or subcutaneous fat

[c] Livers removed from fish during off-loading at Terminal Island, Los Angeles, Nov. 22, 1965.

MONS 064538

Table 4. DDT Concentrations in Selected Tissues and Total Body Weight of Bluefin Tuna

Tissue	N	Correlation Coefficient	Regression Coefficient
liver	9	0.8284, $P < 0.01$	0.0583
		>0.001	±0.0329
X-section	7	0.9678, $P < 0.001$	0.0939
			±0.0255
viscera, except liver	4	0.8558, $P > 0.1$	0.0227
			±0.0323

MCNS 064539